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(54) **Decomposition of volatile organic halogenated compounds contained in gases and aqueous solutions.**

(57) The invention is a method and apparatus for decomposing volatile organic compounds contained in contaminated gases and aqueous solutions. Volatile organic halogenated compounds contained in aqueous solution are removed by volatilizing the compounds from the solution to a gaseous carrier and passing the gaseous carrier through a porous adsorbent bed of silica gel while irradiating the bed with ultraviolet light and/or exposing the bed to ozone. Volatile organic halogenated compounds in a gas are removed by passing the gas through a porous adsorbent bed of silica gel while irradiating the bed with ultraviolet light and/or exposing the bed to ozone.

**EP 0 360 941 A2**

28

## DECOMPOSITION OF VOLATILE ORGANIC HALOGENATED COMPOUNDS CONTAINED IN GASES AND AQUEOUS SOLUTIONS

The invention relates to methods and apparatus for decomposing volatile organic compounds contained in contaminated gases and aqueous solutions using silica gel in combination with ultraviolet light and/or ozone.

Although it is well known that ultraviolet light decomposes volatile organic, halogenated compounds contained in gases (See, U.S. Patent Nos. 4,144,152 and 4,210,503), the rate of decomposition of these compounds has proven unsatisfactory when used in a system in which these compounds are volatilized from a rapidly flowing, aqueous solution and then treated with the ultraviolet light. When ultraviolet light is used for decomposition in such systems, the ultraviolet light does not have sufficient time to effect appreciable decomposition of the continuously flowing halogenated compounds.

Flowing, aqueous systems containing these toxic, undesirable compounds appear in a variety of situations; for example, well water often contains these compounds and therefore must be purified prior to consumption. Additionally, a wide variety of industrial effluent solutions contain these compounds, one example being the waste water contaminated with halogenated solvents. These compounds are toxic and therefore must be removed. Known detoxification systems typically volatilize the halogenated compounds from flowing solution into air; the contaminated air is then released to the atmosphere thereby causing toxic air pollution.

Thus, what is needed is an apparatus and a method which decomposes these toxic compounds quickly enough to serve as an effective pollution control device. The apparatus and method should also be suitable for use as an air and water purification system.

### SUMMARY OF THE INVENTION

The invention provides a method and apparatus for decomposing volatile, organic halogenated compounds contained in gases and aqueous solutions.

One aspect of the invention is an apparatus for decomposing organic compounds contained in gases and aqueous solutions, comprising:

a) a reactor tank for simultaneously exposing a contaminated aqueous solution to ozone and ultraviolet radiation to oxidize organic compounds in the solution and to volatilize organic compounds from the solution, said reactor tank having at least one influent port for incoming solution and at least one effluent port for outgoing solution, and said reactor tank having at least one gas diffuser tube proximal to the influent port for introducing ozone into the contaminated solution in the tank, and said reactor tank containing ultraviolet irradiation means;

b) ozone generator means coupled to at least one gas diffuser tube for generating ozone from air to produce an ozone-air mixture, and for introducing the ozone-air mixture into said reactor tank for reaction with the contaminated solution; and

c) a detoxification unit coupled to the reactor tank for decomposing volatilized organic halogenated compounds contained in gases, said detoxification unit having a plurality of irradiating means for irradiating the volatilized organic compounds, and having a porous adsorbent bed for adsorbing ozone and organic compounds arranged such that said porous adsorbent bed is surrounding said irradiating means and at a distance effective to promote reduction of said volatile organic halogenated compounds in said gases.

The irradiating means may be ultraviolet lamps and may be enclosed in quartz sheaths.

The porous adsorbent bed is preferably silica gel, and may include means for heating the adsorbent bed.

Another aspect of the invention is an apparatus for decomposing volatile organic compounds contained in gases comprising:

a) a housing having a gas supply port, a gas exhaust port, and a gas flow path between said gas supply port and said gas exhaust port;

b) a porous adsorbent bed located in said gas flow path, wherein said porous adsorbent bed is capable of adsorbing ozone and volatile organic halogenated compounds from the gaseous state; and

c) means for irradiating said porous adsorbent bed with ultraviolet light, said porous adsorbent bed surrounding said irradiating means and at a distance effective to promote reduction of said volatile organic compounds in gases. This aspect of the invention may also comprise means for exposing said porous

adsorbent bed to ozone.

Yet another aspect of the invention is an apparatus for decomposing volatile organic halogenated compounds contained in gases comprising:

- a) a housing having a gas supply port, a gas exhaust port, and a gas flow path between said gas supply port and said gas exhaust port;
- b) a porous adsorbent bed located in said gas flow path, wherein said porous adsorbent bed is capable of adsorbing ozone and volatile organic halogenated compounds from the gaseous state; and
- c) means for exposing said porous adsorbent bed to ozone to promote reduction of said volatile organic compounds in said gases.

Another aspect of the invention is a method for decomposing volatile organic halogenated compounds contained in gases comprising passing gas carrying the volatile organic compounds through a porous adsorbent bed of silica gel while irradiating the porous bed with ultraviolet light and/or exposing the porous adsorbent bed to ozone for an amount of time effective to appreciably decompose the volatile organic halogenated compounds in said gases.

Yet another aspect of the invention is a method for decomposing volatile, toxic compounds contained in aqueous solutions comprising:

- a) volatilizing the volatile, toxic compounds from a contaminated aqueous solution to a gaseous carrier by passing said gaseous carrier through said aqueous solutions; and
- b) passing said gaseous carrier through a porous adsorbent bed of silica gel while exposing said porous adsorbent bed to ultraviolet light and/or ozone to appreciably decompose the volatile organic halogenated compounds in said gases.

This aspect of the invention may have the aqueous solution continuously flowing and may further comprise recycling the gaseous carrier to further remove toxic compounds by returning the gaseous carrier to the continuously flowing aqueous solution to volatilize the volatile, toxic compounds and passing said returned gaseous carrier through the porous adsorbent bed while exposing said porous adsorbent bed to ultraviolet light and/or ozone.

It is thus an object of the invention to provide a sufficient rate of decomposition of volatile organic halogenated compounds so that such compounds volatilized from a flowing solution, or contained in flowing gaseous systems can be completely or substantially decomposed.

Other features and advantages of the present invention will become apparent from the following, more detailed description which illustrates, by way of example, the principles of the invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a system for removing volatile organic halogenated compounds from potable water.

FIG. 2 shows a system for removing phenol and volatile organic halogenated compounds from wastewater produced following paint stripping.

FIG. 3 shows an apparatus which was used to test the efficacy of the invention.

FIG. 4 shows a detoxification unit for use in the systems of FIGS. 1 and 2.

FIG. 5 is a sectional view of the detoxification unit of FIG. 4 taken along the lines 5-5.

FIG. 6 is a sectional view of the detoxification unit of FIG. 4 taken along the lines 6-6.

#### DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, a system 10 is shown suitable for purifying a water supply containing trichloroethylene in concentrations of from 15 to 40 parts per billion. The system 10 has a water influent port 12, typically admitting 20 to 30 gallons per minute, a reactor tank 14 with a series of baffles 16, and a water effluent port 18. The water contaminated with trichloroethylene flows into influent port 12 through baffles 16, and out through effluent port 18. Baffles 16 do not extend across the entire width of reactor tank 14, rather baffles 16 are disposed in the tank 14 such that the water flows around the sides of baffles 16; this baffle design prevents back-mixing of contaminated with decontaminated water and may also enhance ozone diffusion throughout the water in tank 14.

The reactor tank 14 is equipped with thirty 40 Watt ultraviolet lamps 20 which provide electromagnetic radiation which includes some wavelengths from 185 nanometers to 254 nanometers. The portion of tank 14 near the influent port 12 has two tubular diffuser inlets 22 which admit an ozone/air mixture, produced by an

ozone generator 24, into tank 14 and also aid in dispersing this mixture throughout the solution in tank 14. The ozone/air mixture in tank 14 acts in conjunction with the known decomposing action of the ultraviolet light produced by the lamps 20 and oxidizes most of the trichloroethylene in solution.

A compressor 26 provides air to ozone generator 24 and a dryer 28 is positioned between compressor 26 and ozone generator 24 to ensure that the ozone generator's efficiency is not impeded by the presence of water in the air supply.

Following treatment of the water with ozone and ultraviolet light, the trichloroethylene and other volatile compounds volatilized by the ozone/air mixture are pumped to a detoxification unit 29 by means of a compressor 30. Detoxification unit 29 is essentially a column of porous silica gel (quartz chips can also be used with the invention) wherein six 40 watt ultraviolet lamps 31 are positioned to irradiate the column. As will be discussed further later, it has been discovered that passing gases carrying volatile organic halogenated compounds (such as the trichloroethylene) through a bed of silica gel or quartz chips and irradiating the bed with ultraviolet light, substantially enhances the rate of decomposition of these compounds. Thus, detoxification unit 29 decomposes the trichloroethylene not decomposed by the action of the ultraviolet light and the ozone in reactor tank 14; near complete decomposition of the toxic trichloroethylene results.

Following treatment by detoxification unit 29, the resulting gases, which include some ozone, are pumped by a compressor 30 to a degasser 32. Degasser 32 has substantially detoxified water -- which has had the volatile organic halogenated compounds volatilized from it and which has also been treated with ozone and ultraviolet light within reactor tank 14 -- flowing to it from the effluent end of tank 14. Degasser 32 employs six ultraviolet lamps 34 to provide ultraviolet light which decomposes residual ozone. An air inlet port 36 is also provided on degasser 32 to add make-up air to the system.

A level gauge 37 is associated with degasser 32 and when degasser 32 becomes filled with detoxified water, a feed back system between level gauge 37 and a centrifugal pump 38 turns on pump 38 and water is pumped from the bottom of degasser 32 back to reactor tank 14. The water pumped back will contain any un-volatilized or un-decomposed halogenated compounds; thus, these compounds are returned to the system for further treatment and oxidation.

Air, which has had the ozone removed therefrom by degasser 32, is returned to compressor 26 which mixes make-up air with the recycled air. Compressor 26 pumps the gaseous mixture to air dryer 28 which in turn feeds dried air to an ozone generator 24; thus, no gases or volatile organics are vented to the atmosphere.

It can be seen that a cost-efficient system which decomposes nearly all the toxic trichloroethylene in drinking water is provided. Because the detoxification unit 29 can also decompose other volatile organic halogenated compounds, for example: carbon tetrachloride; tetrachloroethylene; vinyl chloride; ethylene dibromide; methylene chloride, 1,1,1-trichloroethane; chlorobenzene; hexachloroethane; 1,1-dichloroethane; 1,1,2-trichloroethane, 1,1,2,2-tetrachloroethane; bis(chloromethyl) ether; bis (2-chloroethyl) ether; 2-chloroethyl vinyl ether (mixed); chloroform; 1,2-dichlorobenzene; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 1,1-dichloroethylene; 1,2-trans-dichloroethylene; 1,2-dichloropropane; 1,2-dichloropropylene; bis (2-chloroisopropyl) ether; bis (2-chloroethoxy) methane; methyl chloride; methyl bromide; bromoform; dichloro dichlorobromomethane; trichlorobromomethane; trichlorofluoromethane; dichloro fluoromethane; chlorodibromomethane; this same system can be used to detoxify water contaminated with any of these compounds.

Referring to FIG. 2, a system 100 is shown suitable for removing methylene chloride and phenol from waste water -- both compounds are typical by-products of paint stripping. Waste water, contaminated with up to 4,000 parts per million of methylene chloride and also contaminated with phenol, is pumped by a pump 110 from a tank 112 at a rate of 3 to 4 gallons per minute. The water passes through a heat exchanger 116 and is then preheated to about 75 to 80 °C by a heater 118; thereafter it enters a reactor tank 114. Reactor tank 114 is equipped with a set of internal heaters 120 which maintain the reaction temperature of the waste water. Maintaining the reaction temperature enhances oxidation of phenol and also may serve to enhance the rate of methylene chloride vaporization and decomposition.

Reactor tank 114 is provided with an impermeable wall 122 which divides tank 114 into first and second sections 124 and 126, respectively. First section 124 houses internal heaters 120 as well as four baffles 128. The baffles 128 are designed to extend only part-way across tank 114 in order to prevent back-mixing of the water. This design may also enhance dispersion of gases which enter tank 114 through a set of tubular diffusers 140. Tank 114 is also equipped with an air inlet 130 to provide make-up air to the system. Tank 114 can be provided with a levelling gauge 131 to indicate the water level in the tank.

A compressor 132 pumps air, carrying methylene chloride volatilized by the gases entering through tubular diffusers 140, from the top of tank 114 into a detoxification unit 134. Detoxification unit 134 is

essentially the same as detoxification unit 29. Detoxification unit 134 is designed to decompose the volatilized methylene chloride and is essentially a porous bed of silica gel (or quartz chips) irradiated with eight 40 Watt ultraviolet lamps 135 which provide ultraviolet light. The ultraviolet light includes some wavelengths from 185 nano-m to 254 nano-m. Due to the similarity between detoxification unit 134 and detoxification unit 29, system 100 can decompose all the same volatile organic halogenated compounds which can be decomposed by system 10.

It can be seen in FIG. 2 that prior to entry of the waste water into tank 114, a solution of  $H_2O_2$  and  $FeSO_4$  (pumped from a tank 136 by a diaphragm pump 138) is added to the waste water. This solution serves to oxidize the phenol and, as discussed previously, works best when the waste water is heated.

It should be noted that paint stripping waste water typically contains traces of the following elements.

ELEMENT	CONCENTRATION (ppm)
Chromium	51.0
Zinc	10.0
Copper	0.05
Nickel	0.06
Cadmium	0.02
Lead	0.2

The addition of the  $FeSO_4$ , which acts as an oxidation catalyst for phenol, may be unnecessary as one or more of these elements which already are in the waste-water could act as the phenol oxidation catalyst.

Following treatment in detoxification unit 134, compressor 132 pumps the gases from the top of unit 134 and through a series of tubular diffusers 140 which bubble the gases into first section 124 of tank 114. The gases so treated will be almost completely free of methylene chloride which has been decomposed to, inter alia, formic acid. FIG. 2 shows that the gases are pumped by compressor 132 from near the midpoint of first section 124. After the waste-water has passed through the first two of the four baffles 128 and is near the midpoint of first section 124, most of the halogenated compounds have been volatilized from the water; thus, water near wall 122 is essentially detoxified. The gases treated in unit 134 are returned to all portions of first section 124; however, these gases have been detoxified and therefore do not add to the toxicity of the water near wall 122.

The detoxified water near wall 122 is pumped by a centrifugal pump 142 into second section 126 of tank 114. Also entering second section 126 through a set of tubular diffusers 144 is ozone produced by an ozone generator 146. The detoxified water and ozone are mixed in second section 126 of oxidize the intermediate aliphatic acids produced by the oxidation of phenol. Ozone then passes from the top of second section 126 into an ozone decomposer 152 which produces oxygen and releases it to the atmosphere.

Air entering ozone generator 146 first passes through an air filter 148 and an air dryer 150 which respectively filter and then dry the entering air. Water is pumped into ozone generator 146 in order to cool the generator.

Second section 126 is generally nearly full of water -- first section 124 is usually about one-half full and has a layer of foam, atop the water -- and water is pumped from near the top of second section 126 through an effluent port 154. The effluent water is thus free (or nearly free) of phenol, methylene chloride and formic acid and is safe for environmental release.

It can be seen that the water exiting second section 126 will be at an elevated temperature as it has been heated at several points along its flow route. Heat exchanger 116 uses the heat of the effluent water to aid in pre-heating the influent water prior to its entry into tank 114 and energy is thereby conserved. Alternatively, water exiting second section 126 can pass through a by-pass 156 which circumvents heat exchanger 116 and channels the effluent water to tank 114 for re-purification.

Second section 126 can also be equipped with a level gauge 155, and system 100 can be provided, at any of a number of locations, with water flow meters and water temperature indicators (not shown). Compressor 132 can be equipped for flow control with a by-pass 158 which allows the gases flowing from detoxification unit 134 to flow around, rather than through, compressor 132.

It would also be possible to use system 100 for detoxification of waste water which contains volatile organic halogenated compounds but contains no phenol. For treatment of phenol-free waste water one would simply not add the  $H_2O_2$  and the  $FeSO_4$  to the waste water.

Description of a Detoxification Unit

Referring to FIG. 4, a system 306 is shown. System 306 includes a model detoxification unit 308 having a toxic air supply port 310 and an exhaust port 312 and further includes an electrical control panel 314, a power supply 316 and power lines 318, 320, and 321. Detoxification unit 308, electrical control panel 314 and a compressor 322, which pumps the toxic air or gases into detoxification unit 308, all rest on a base 326.

The detoxification unit 308, along with the other portions of system 306, can be used as the detoxification unit portion of either of systems 10 or 100.

Referring to FIG. 5, a sectional view of detoxification unit 308 taken along the lines 5-5, is shown. Detoxification unit 308 has a housing 328 with caps 330 and 332, respectively, affixed to the upper and lower ends of housing 328. Housing 328 provides a hermetic seal around a 6 to 16 mesh porous silica gel bed 334 (alternatively, a porous bed of quartz chips can be used) and also around a plurality of 40 watt low pressure, high intensity, ultraviolet lamps 336. Toxic gases flow through air supply port 310, through the silica gel bed 334, and out through exhaust port 312. The ultraviolet light provided by lamps 336 irradiates silica gel bed 334 and acts to aid in decomposing any volatile organic halogenated compounds in the gases. Lamp leads 338 and 340 respectively positioned in mouths 342 and 344, supply power to the lamps 336 from the power lines 321 and 320.

Referring to FIG. 6, a sectional view of detoxification unit 308 taken along the lines 6-6 is shown. FIG. 6 shows forty-eight lamps 336; a greater or a lesser number of lamps can be used in other embodiments of the invention.

## EXAMPLE I

The Efficacy of the Detoxification Unit

Prior to developing systems 10 and 100, both of which are suitable for commercial applications, the inventors performed experiments with a prototype detoxification unit to determine the unit's efficacy in decomposing volatile organic halogenated compounds.

In a set of experiments, the results of which are summarized at Table A, the efficacy of decomposing volatile organic halogenated compounds carried by gases, wherein the gases are passed through a bed of silica gel which is irradiated with ultraviolet light, was conclusively demonstrated.

In the experiments summarized at Table A, a 1 inch diameter embodiment of a detoxification unit, similar in all other respects to 2 inch embodiment of a detoxification unit 212 seen in FIG. 3, was used. A cylinder of compressed air and vinyl chloride, containing 53 ppm vinyl chloride, released the compressed mixture at 4 liters/minute for 15 minutes into the detoxification unit. The products were thereafter passed through a charcoal bed. Charcoal is known to absorb vinyl chloride; therefore undecomposed vinyl chloride was trapped in the bed. Gas chromatography was performed on the charcoal to determine the amount of undecomposed vinyl chloride and from this determination the percentage of decomposition can be readily seen.

TABLE A

RUN NO.	CONDITIONS	PERCENTAGE OF VINYL CHLORIDE FOUND IN TRAP
1	Detoxification unit by-passed by the compressed mixture.	100%
2	Mixture passes through the detoxification unit.	0.03%
3	Mixture passes through the detoxification unit but the UV light is off.	36%
4	Mixture passes through detoxification unit but the silica gel bed has been removed from detoxification unit, U.V. light is on.	5.8%

Thus, comparing the amount trapped shown in Run No. 4 (without silica gel), to the amount trapped in Run No. 2 (using ultraviolet light irradiation of the silica gel bed), one can see that a considerably greater percentage of the vinyl chloride is destroyed when using ultraviolet light irradiation of the silica gel bed.

Another series of experiments were performed all of which involved passing air carrying organic halogenated compounds through a silica gel bed which is irradiated with ultraviolet light; the results are summarized on Table 1.

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TABLE 1  
DESTRUCTION OF ORGANIC HALOGENATED COMPOUNDS BY DETOXIFICATION UNIT

Model compound	D-Tox diameter (inches)	Number of runs	Treatment conditions				Level of Toxic compounds at start	Amounts after Treatment		Percent destroyed		
			Air		Water			In Trap	In Solution			
			Type	Flow (L/min)	Type	Flow (L/min)						
TCE <sup>3</sup>	2	5	Open	6	Batch	1.0	None	5.0 ppm	5 mg	0.15 mg (pentane)	N.D.	97
TCE <sup>3</sup>	2	1	Open	2	Batch	1.0	None	4.0 ppm	4 mg	0.05 mg (pentane)	N.D.	99
TCE <sup>3</sup>	2	2	Open	2	Batch	1.0	None	1.5 ppm	1.5 mg	0.037 mg (pentane)	N.D.	98
TCE <sup>3</sup>	2	11	Open	4	Batch	1.0	None	5.0 ppm	5 mg	0.17 mg (pentane)	N.D.	97
TCE <sup>4</sup>	2	6	Open	4	Batch	1.0	Kene	5.0 ppm	5 mg	0.23 mg (pentane)	N.D.	96
EDB	2	9	Open	4	Batch	1.0	None	5.0 ppm	5 mg	0.077 mg (MeOH)	N.D.	98
<hr/>												
TCE <sup>3</sup>	1.5	1	Cyclic	30	Batch	3.3	None	5.0 ppm	16.5 mg	N/A	0.18 mg	99
TCE <sup>3</sup>	1.5	1	Cyclic	10	Batch	3.3	None	1.0 ppm	1.8 mg	N/A	0.05 mg	97
TCE <sup>4</sup>	1	1	Cyclic	7.5	Batch	0.85	None	5.0 ppm	4.2 mg	N/A	0.0034 mg	99
EDB	1	1	Cyclic	7.5	Batch	0.85	Kene	5.0 ppm	4.2 mg	N/A	0.26 mg	94
TCA	1	1	Cyclic	7.5	Batch	0.85	Kene	5.0 ppm	4.2 mg	N/A	0.18 mg	96
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TCE <sup>3</sup>	1	2	Open	10	Flow	N/A	0.5	5.0 ppm	188 mg	4 mg (MeOH)	0.03 mg/100 ml	94
TCE <sup>3</sup>	1	13	Open	45	Flow	N/A	1.0	5.0 ppm	250 mg	25 mg (MeOH)	**	85
TCE <sup>3</sup>	2.5	4	Open	9	Flow	N/A	0.9	5.0 ppm	810 mg	46 mg (toluene)	**	90
TCE <sup>4</sup>	2.5	4	Open	9	Flow	N/A	0.9	5.0 ppm	810 mg	72 mg (toluene)	**	89
TCA	2.5	4	Open	9	Flow	N/A	0.9	5.0 ppm	810 mg	69 mg (toluene)	**	85



TABLE 1 (continued)

Model compound	D-Tox diameter (inches)	Number of runs	Treatment conditions				Level of Toxic compounds at start Concentration	Total amount	Amounts after Treatment	
			Time (min)	Air Type	Water Type	Flow (L/min)			In Trap	In Solution
DNCP	1.5	4	180	Cyclic	19 Flow	N/A	0.25	0.09 mg	..	0.028 mg
DBCP	1.5	1	45	Cyclic	19 Flow	N/A	0.10	0.009 mg	..	0.0025 mg
CH <sub>2</sub> =CHCl	1	3	3	Open	4	N/A	N/A	636 mg	N.D.	N/A

\* The solvent used in the traps is given in parenthesis.

\*\* Indicates the amount of the toxic compound in solution after the treatment was not measured, however, analyses of the treated solutions under the same conditions indicated more than 95% removal of the model compounds.

\*\*\* In the case of vinyl chloride the trap consisted of a charcoal column rather than a solvent.

N.D. means none was detectable.

N/A means not applicable

TCL<sub>3</sub> = trichloroethylene

TCP<sub>4</sub> = tetrachloroethylene

EDB = ethylene dibromide

TCA = 1,1,1, trichloroethane

DBCP = 1,2,dibromo-3,chloropropane

CHCl = vinyl chloride

Referring to FIG. 3, a basic catalytic decomposition test apparatus 210 which was essentially the apparatus used to perform the experiments summarized at Table 1, is shown. Tank 216 and bottles 218 contain aqueous solutions of the volatile organic halogenated compounds and air carrying these compounds was volatilized from either tank 216 or bottles 218.

A variety of embodiments of test apparatus 210 were used. Valves A to H are shown to schematically indicate the different flow paths of the air carrying these compounds when this air passed through the different embodiments of test apparatus 210. Referring to Table 1, in the first, third and fifth group of experiments the air flow was "open", meaning that the air flowed along flow path 219 from the bottom of detoxification unit 212 to the scrubber bottles 214. Bottles 214 trap undecomposed organic halogenated compounds. In these groups of experiments no air flowed from unit 212 to either the tank 216 or to the bottles 218, this can be envisioned by closing valves A and B and opening valve H.

In the second and fourth group of experiments, the air flow was "cyclic", indicating that the air was pumped by compressor 225 along flow path 223 or 221 and was then returned to either of tank 216 or bottles 218. This can be envisioned by opening valves A or B and closing valve H.

Detoxification unit 212 is essentially a hermetic cylindrical housing with an ultraviolet lamp 220 extending through the center thereof, and with a granular silica gel bed 222 surrounded by heating tape 224. Heating tape 224, which heats silica gel bed 222, was activated between runs and nitrogen gas was simultaneously passed through silica gel bed 222. Although this heating/nitrogen treatment temporarily improved the efficacy of the detoxification unit, good results were also obtained without this treatment.

In the various runs of the experiments summarized in Table 1, air flowing from one of tank 216 or bottles 218 flows to the top of detoxification unit 212, through silica gel bed 222, and out through the bottom of detoxification unit 212. Several different embodiments of detoxification unit 212 were used with these experiments. Unit 212 shown in FIG. 3 has a 2 inch housing diameter; other embodiments of the detoxification unit had various housing diameters as indicated at Table 1. A make-up air inlet 230 is shown which can be used to add lost air to the system.

One can envision the bottles 218 not being used by closing valve G, indicating there is no gas flow along path 227 and then tank 216 supplied the gases to the system through open path 233. It is immaterial to the results which of tank 216 and bottles 218 were used with the various experimental runs as both are equivalent in function; therefore there is no indication in Table 1 which actually was used.

Valves C and F, and D and E, are shown to schematically indicate that there were two further different embodiments of unit 212, one of which allowed air flow through the sides of unit 212 (indicated schematically by opening valves C and E) and one of which allowed air flow through the top and bottom of the unit 212 (indicated schematically by opening valves F and D). The embodiment of unit 212 actually used is immaterial to the experimental results and is therefore not indicated in Table 1.

Valves I and J, and K and L, are shown to indicate that water can be flowing through one of flow paths 229 and 231, or can be batched, as indicated in Table 1.

In the case of vinyl chloride ( $\text{CH}_2 = \text{CHCl}$ ), this compound was not volatilized from a solution in tank 216 or bottles 218 but rather was released from a compressed cylinder containing a mixture of air and vinyl chloride. The mixture was passed through the detoxification unit 212 and then to a charcoal column trap (not shown) rather than to bottles 214.

The "percent destroyed" column of Table 1 shows that the detoxification unit 212 effectively decomposed all of the organic halogenated compounds which were tested. In a set of runs initially performed with test apparatus 210, at one point there appeared to be a downward trend in the percentage of halogenated compound decomposition. Another run was performed and thereafter nitrogen gas was passed through the bed to determine if the nitrogen gas could regenerate the bed to full decomposing activity. The rate of decomposition increased back to about 98% indicating that a regeneration effect had in fact occurred.

Based on the result of the experiments summarized in Table 1 and Table A, it is hypothesized that the silica gel bed performs two functions which aid in halogenated compound decomposition:

(1) The bed absorbs and concentrates the compounds on a large surface area to allow decomposition by ultraviolet light of the accessible, concentrated compounds;

(2) The bed also seems to have a catalytic effect which enhances the decomposition by ultraviolet light.

Thus the prototype detoxification unit, employing silica gel irradiated with ultraviolet light and/or exposed to ozone, can be used in a wide variety of systems in modified forms to destroy a wide variety of volatile organic halogenated compounds. It is believed that any organic halogenated compound which can be decomposed by ultraviolet light and/or ozone and which can be volatilized from aqueous solution, can be

decomposed by the detoxification unit. Such volatile organic halogenated compounds include, but are not limited to: tetrachloroethylene; vinyl chloride; carbon tetrachloride; ethylene dibromide; methylene chloride, 1,1,1-trichloroethane; chlorobenzene; hexachloroethane; 1,1-dichloroethane; 1,1,2-trichloroethane, 1,1,2,2-tetrachloroethane; chloroethane; bis(chloromethyl ether; bis (2-chloroethyl) ether; 2-chloroethyl vinyl ether (mixed); chloroform; 1,2-dichlorobenzene; 1,3-dichlorobenzene; 1,4-dichlorobenzene; 1,1-dichloroethylene; 1,2-transdichloroethylene; 1,2-dichloropropane; 1,2-dichloropropylene; bis (2-chloroisopropyl) ether; bis (2-chloroethoxy) methane; methyl chloride; methyl bromide; bromoform; dichlorobromomethane; trichlorobromomethane; trichlorofluoromethane; dichlorofluoromethane; chlorodibromomethane; and 1,2,dibromo-3, chloropropane.

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## EXAMPLE II

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### Detoxification Unit Using a Bed of Quartz Chips

Once it was determined that the silica gel bed in combination with ultraviolet light did increase rate of trichloroethylene destruction, a slightly modified apparatus, similar in function to a conventional counter-current air stripping tower, was fabricated. The modified apparatus (not shown) passed water downwardly through a column of aluminum chips and passed air upwardly through the column. The air then flowed to a one-inch diameter detoxification unit which had either a bed of silica gel or porous quartz chips irradiated by ultraviolet light, and was in all other respects the same as the two-inch diameter detoxification unit 212 seen in FIG. 3.

Using this apparatus, it was demonstrated that the bed of quartz chips also enhanced the rate of trichloroethylene decomposition, however, the rate did not increase to as high a level as that observed when a silica gel bed was used.

The results of these experiments in which the halogenated compounds were stripped from water in an aluminum chip column by counter-current air flow, in combination with the results of the experiments summarized in Table 1 and Table A, shows that the detoxification unit of this invention could accept and purify contaminated air from a conventional counter-current water/air stripping tower. Contaminated air flowing from water/air stripping tower is generally simply released to the atmosphere.

Other experiments also demonstrated that the detoxification unit of this invention could decompose volatile organic halogenated compounds carried by any of dry, humid or water saturated air.

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## EXAMPLE III

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### 185 Nanometer Wavelength Light

The ultraviolet light used when performing all these experiments contained a plurality of wavelengths, including some wavelengths between 185 nanometers to 254 nanometers. A set of unreported experiments was conducted to determine if the wavelengths of the ultraviolet light affected the rate of halogenated compound decomposition. In these experiments, described in greater detail below, ozone was added to a solution of organic halogenated compounds and the solution was irradiated with ultraviolet light.

An aqueous solution of organic halogenated compounds was introduced into a reactor tank with one centrally located 40 watt ultraviolet lamp. Through the bottom of the tank was fed a mixture of ozone/oxygen, or ozone/air, or ozone/nitrogen.

Two different 40 watt ultraviolet lamps were used with these experiments, both of these lamps emitted the major part of their energy at 254 nanometers. One of these two lamps also emitted some of its energy at 185 nanometers energy, but less than 1% of the total. The lamp with the 185 nanometers component increased the oxidation rate of 1,2,dibromo-3, chloropropane, various PCBs, Lindane and hexachlorobenzene, three-fold as compared with the oxidation rate achieved with the lamp which did not have the 185 nanometers component. Thus the oxidation rate of these halogenated compounds is increased by increas-

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ing the proportion of energy at 185 nanometers. These results can reasonably be extrapolated and it can be seen that the decomposition rate of other halogenated compounds would also likely be increased by lamps which emit more than 1% of their energy at 185 nanometers. However, when using lamps which either emitted some energy at 185 nanometers, or did not emit any, for the ultraviolet-ozonation of pentachlorophenol, the oxidation rate was only about 10% greater than the oxidation rate achieved when using ozone in the absence of ultraviolet light.

## EXAMPLE IV

Elevating the Temperature of Solution

In a set of experiments summarized at Table 2, it was demonstrated that the oxidation rate of certain organic compounds in aqueous solution, when  $H_2O_2$  is added to the solution and it is thereafter irradiated with ultraviolet light, was enhanced by elevating the temperature of solution to  $80^\circ C$ .

TABLE 2

OXIDATION OF ORGANICS WITH UV/H <sub>2</sub> O <sub>2</sub> at 80 ° C				
Compounds Oxidized	Time <sup>**</sup> (min)	Temp ( ° C)	Number of Runs	Total of Organic Carbon <sup>***</sup> (ppm)
Fatty acids	0	80	6	33,300
	480	80		12,700
	780	80		7,200
Fatty acids	0	RT	1	33,300
	480	RT		23,400
Naphthenic acids	0	RT	1	430
	120	RT		215
Naphthenic acids	0	80	2	430
	120	80		42
* RT indicates the reaction was carried out at room temperatures.				

<sup>\*\*</sup> Time indicates the time of treatment with ultraviolet light (in minutes)

<sup>\*\*\*</sup>Compound concentrations are listed in "Total of Organic Carbon" at start of treatment (time = 0), and following treatment for the times specified.

Comparing the tests done at room temperature with those done at  $80^\circ C$  it can be seen that elevating the reaction temperature increased the oxidation rate of all the compounds listed on Table 2. In a set of unreported experiments it was shown that elevating the reaction temperature to  $80^\circ C$  also increased the oxidation rate (in a system using ultraviolet light and  $H_2O_2$  for oxidation) of solutions of the following compounds:

- c) formaldehyde and formic acid;
- d) citric acid and oxalic acid;
- e) phenol and methylene chloride;

f) phenol and isopropyl alcohol. It was observed that the oxidation rate of certain long chain alcohols was not enhanced by elevating the temperature when using ultraviolet light and  $H_2O_2$ .

In another set of experiments it was shown that the rate of oxidation of certain compounds in aqueous solution, when using irradiation of the solution with ultraviolet light and addition of ozone to the solution, was enhanced by elevating the solution temperature to  $80^\circ C$ . The results are summarized at Table 3.

TABLE 3

OXIDATION OF ORGANICS WITH UV/O3 at 80 ° C				
Compounds Oxidized (major constituents)	Time <sup>**</sup> (min)	Temp. (° C)	TOC <sup>***</sup> (ppm)	Number of runs
Phenol + methylene chloride	0	RT <sup>*</sup>	5310	1
	150	RT	5680	
	260	RT	4520	
Phenol + methylene chloride	0	80	5310	1
	150	80	5167	
	260	80	2372	
Naphthenic acids	0	RT	141	1
	60	RT	76	
	90	RT	10	
Naphthenic acids	0	80	141	2
	60	80	34	
	90	80	N.D. <sup>****</sup>	
Naphthenic acids	0	80	340	3
	120	80	60	

\* RT indicates the reaction was carried out at room temperature.

\*\* Time, indicates time of treatment with ultraviolet light (in minutes)

\*\*\* TOC means total of organic carbon concentration at start of treatment (time = 0), and following treatment for the times specified.

\*\*\*\*N.D. means none was detectable.

Comparing the tests done at room temperature with those done at 80 ° C, it can be seen that elevating the temperature increases the oxidation rate. In a set of unreported experiments it was shown that the oxidation rate of both Butachlor and EDTA (when using ultraviolet light and ozone for oxidation) was also increased by elevating the temperature to 80 ° C.

It was also observed that when using this system, the oxidation rate of long chain alcohols was not increased by elevating the temperature.

#### EXAMPLE V

Additional experiments were performed with a prototype detoxification unit to demonstrate the unit's efficacy in decomposing volatile organic halogenated compounds with ultraviolet light and/or ozone exposure. In this series of experiments, a 1.3 inch diameter embodiment of a detoxification unit similar to detoxification unit 212 as seen in Fig. 3 was used with the following modifications. The detoxification unit consisted of a glass cylindrical housing containing a column of granular silica gel with glass wool plugs at both ends to retain the silica gel in place, and silicone rubber stoppers at the top and bottom to seal the cylindrical housing. The stoppers were provided with gas inlet and outlet openings. The temperature of the silica gel bed was controlled by means of a heating tape 224 as seen in Fig. 3 wrapped around the outside of the cylindrical housing. A glass cylinder (2 liter capacity) closed at the top was also used in which 1800 ml of water containing trichloroethylene (TCE) was placed. Compressed air from an air pump was passed into the TCE solution in the glass cylinder at selected flow rates, and exited via an outlet tube from the glass cylinder to the bottom of the detoxification unit. An ozone inlet for introducing ozone was provided in the outlet tube exiting from the glass cylinder. Offgas from the glass cylinder containing the TCE solution was thus passed into the detoxification unit through the silica gel column and out the top of the unit. A hexane trap was provided for the gas exiting the detoxification unit to trap any remaining TCE and other volatile compounds. This trap consisted of a gas washing bottle (VWR Scientific Inc., Cerritos, CA) charged

with 200 ml of hexane. Either all or a portion of the offgas from the detoxification unit was passed through this trap.

This test apparatus provided a means for testing a batch of TCE-containing solution. Additional volumes of TCE were introduced into the solution in the glass cylinder at selected time intervals to replenish the TCE in solution for additional test runs. For experiments using ultraviolet irradiation the cylindrical housing included a 40 watt ultraviolet lamp 220 (74 cm long) extending through the center of the cylinder. For experiments using only ozone exposure, the ultraviolet lamp was omitted. The temperature on the tape was controlled by a Variac auto transformer type 3PN1010 (Staco Energy Products Co., Dayton, OH). A thermometer (VWR Scientific Inc.) was installed in the top of the cylinder with the bulb immersed in the silica gel column, and the glass tube was mounted vertically.

In the first set of experiments, the results of which are summarized in Table 4, the efficacy of the removal of volatile organic halogenated compounds in a solution, using compressed air and using TCE as a model compound, wherein air was passed through a silica gel and exposed only to ozone, i.e. not irradiated with ultraviolet light, was conclusively demonstrated.

In the experiments summarized at Table 4, water containing various concentrations (ppm) of TCE, was stripped with air and the air containing the removed TCE was allowed to flow into the detoxification unit and through the same silica gel at a rate of 1 liter/minute (L/M) for 8 minutes. Compressed air was supplied by an air pump at various air flow rates. Ozone input flow and temperature were held constant. Test Run Nos. 1 through 7 employed a concentration of 350 ppb of TCE, an ozone flow in oxygen of 0.3 liters per minute and a silica gel temperature of 40° C. In test Run Nos. 1 through 4, the compressed air flow was 2.3 L/M.

As shown in Table 4, the percent of TCE that passed through the detoxification unit was below one percent. The space velocity in this case was 920 reciprocal hours. In test Run Nos. 5-7, the TCE was maintained at 350 ppb in water but the gas flow rate was increased to 6.3 L/M. As shown, there was a large increase in the amount of TCE that passed through the detoxification unit, starting at 8.9% (2520 reciprocal hours). In Table 4, test Run Nos. 8-16, TCE dosage was reduced from 350 ppb to 50 ppb. All the other parameters were kept constant.

The volume of TCE that passed through the detoxification unit varied from 3% up to 80%. An increase in temperature of 5° C in test Run Nos. 17-20 did not have any significant effect on the removal of TCE in the system.

Because it appeared that saturation of the same silica gel was occurring and limiting removal of the TCE, the silica gel was first partially regenerated by passing nitrogen through the gel at about 1 L/M at 85° C for two hours, then the testing continued using the detoxification unit described above.

TABLE 4

REMOVAL OF TCE FROM WATER FOLLOWED BY OXIDATION OF THE REMOVED TCE WITH O <sub>3</sub> IN A SiO <sub>2</sub> COLUMN IN THE ABSENCE OF UV LIGHT						
Test Run No.	TCE (ppb)	Gas Flow Thru D-TOX (L/M)	2% O <sub>3</sub> /O <sub>2</sub> Flow (L/M)	Temp. (°C)	% of TCE Remaining	Velocity (hr <sup>-1</sup> )
1	350	2.3	0.3 ± 0.05	40	0.45	920
2	350	2.3	0.3 ± 0.05	40	0.39	920
3	350	2.3	0.3 ± 0.05	40	0.24	920
4	350	2.3	0.3 ± 0.05	40	0.35	920
5	350	6.3	0.3 ± 0.05	40	8.9	2520
6	350	6.3	0.3 ± 0.05	40	18	2520
7	350	6.3	0.3 ± 0.05	40	25	2520
8	50	6.3	0.3 ± 0.05	40	80	2520
9	50	6.3	0.3 ± 0.05	40	33	2520
10	50	6.3	0.3 ± 0.05	40	20	2520
11	50	6.3	0.3 ± 0.05	40	3.0	2520
12	50	6.3	0.3 ± 0.05	40	11	2520
13	50	6.3	0.3 ± 0.05	40	36	2520
14	50	6.3	0.3 ± 0.05	40	20	2520
15	50	6.3	0.3 ± 0.05	40	47	2520
16	50	6.3	0.3 ± 0.05	40	47	2520
17	50	6.3	0.3 ± 0.05	45	44	2520
18	50	6.3	0.3 ± 0.05	45	36	2520
19	50	6.3	0.3 ± 0.05	45	28	2520
20	50	6.3	0.3 ± 0.05	45	50	2520

Table 5 describes the testing that was done after the partial regeneration of the silica gel. Again, a starting concentration of 50 ppb of TCE was removed from the water solution. The air flow was kept at 6.3 L/M and the ozone input flow was maintained at .3 L/M. The temperature was raised to 50 °C and, as shown in Table 5, the amount of TCE passing through the detoxification unit was below detectable limits up to test Run No. 30. After that, there was again a breakthrough of the TCE, and it was concluded that the silica gel was saturated. The silica gel was again partially regenerated with nitrogen at a rate of 1 L/M at 85 °C for two hours.

TABLE 5

REMOVAL OF TCE FROM WATER FOLLOWED BY OXIDATION OF THE REMOVED OFF TCE WITH O <sub>3</sub> IN A SiO <sub>2</sub> COLUMN IN THE ABSENCE OF UV LIGHT						
Test Run No.	TCE (ppb)	Gas Flow Thru D-TOX (L/M)	2% O <sub>3</sub> /O <sub>2</sub> Flow (L/M)	Temp. (° C)	% of TCE Remaining	Velocity (hr <sup>-1</sup> )
21	50	6.3	0.3 ± 0.05	50	0	2520
22	50	6.3	0.3 ± 0.05	50	0	2520
23	50	6.3	0.3 ± 0.05	50	0	2520
24	50	6.3	0.3 ± 0.05	50	0	2520
25	50	6.3	0.3 ± 0.05	50	0	2520
26	50	6.3	0.3 ± 0.05	50	0	2520
27	50	6.3	0.3 ± 0.05	50	0	2520
28	50	6.3	0.3 ± 0.05	50	0	2520
29	50	6.3	0.3 ± 0.05	50	0	2520
30	50	6.3	0.3 ± 0.05	50	0	2520
31	50	6.3	0.3 ± 0.05	50	16	2520
32	50	6.3	0.3 ± 0.05	50	21	2520
33	50	6.3	0.3 ± 0.05	50	29	2520
34	50	6.3	0.3 ± 0.05	50	34	2520
35	50	6.3	0.3 ± 0.05	50	38	2520
36	50	6.3	0.3 ± 0.05	50	48	2520
37	50	6.3	0.3 ± 0.05	50	48	2520

Table 6 shows the results of tests where the temperature was raised to 60° C. All the other variables were kept at the same levels as in Table 5. In the nineteen tests that were conducted in this series of runs, there was no breakthrough of TCE in the detoxification. It was concluded that a 60° C temperature was required in order to maintain an equilibrium and prevent breakthrough of the TCE through the same silica gel at the operating conditions shown in Table 6.



TABLE 6

REMOVAL OF TCE FROM WATER FOLLOWED BY OXIDATION OF THE REMOVED TCE WITH O <sub>3</sub> IN A SiO <sub>2</sub> COLUMN IN THE ABSENCE OF UV LIGHT						
Test Run No.	TCE (ppb)	Gas Flow Thru D-TOX (L/M)	2% O <sub>3</sub> /O <sub>2</sub> Flow (L/M)	Temp. (°C)	% of TCE Remaining	Velocity (hr <sup>-1</sup> )
38	50	6.3	0.3 ± 0.05	60	0	2520
39	50	6.3	0.3 ± 0.05	60	0	2520
40	50	6.3	0.3 ± 0.05	60	0	2520
41	50	6.3	0.3 ± 0.05	60	0	2520
42	50	6.3	0.3 ± 0.05	60	0	2520
43	50	6.3	0.3 ± 0.05	60	0	2520
44	50	6.3	0.3 ± 0.05	60	0	2520
45	50	6.3	0.3 ± 0.05	60	0	2520
46	50	6.3	0.3 ± 0.05	60	0	2520
47	50	6.3	0.3 ± 0.05	60	0	2520
48	50	6.3	0.3 ± 0.05	60	0	2520
49	50	6.3	0.3 ± 0.05	60	0	2520
50	50	6.3	0.3 ± 0.05	60	0	2520
51	50	6.3	0.3 ± 0.05	60	0	2520
52	50	6.3	0.3 ± 0.05	60	0	2520
53	50	6.3	0.3 ± 0.05	60	less than 1	2520
54	50	6.3	0.3 ± 0.05	60	less than 1	2520
55	50	6.3	0.3 ± 0.05	60	0	2520
56	50	6.3	0.3 ± 0.05	60	0	2520

Further testing was conducted as summarized in Table 7. In test Run Nos. 57-60, the TCE in the water was increased to 700 ppb and all other conditions were maintained the same as in Table 6. Twenty two to 26% of the TCE passed through the same silica gel in this case. In test Run Nos. 61-64, the temperature was raised to 70°C and resulted in a slight increase in the percent of TCE passing through the silica gel. In test Run Nos. 65-70, the temperature was reduced to 60°C, and the ozone input flow was slightly increased to 0.5 L/M. These two changes again did not seem to have a significant effect on the removal of TCE through the silica gel. In test Run Nos. 71-78, the compressed air flow through the silica gel was reduced in increments from 5.5 L/M to 4.5 L/M and then to 3.5 L/M, or a space velocity of 1400 reciprocal hours.

TABLE 7

REMOVAL OF TCE FROM WATER FOLLOWED BY OXIDATION OF THE REMOVED TCE WITH O <sub>3</sub> IN A SiO <sub>2</sub> COLUMN IN THE ABSENCE OF UV LIGHT						
Test Run No.	TCE (ppb)	Gas Flow Thru D-TOX (L/M)	2% O <sub>3</sub> /O <sub>2</sub> Flow (L/M)	Temp. (° C)	% of TCE Remaining	Velocity (hr <sup>-1</sup> )
57	700	6.3	0.3 ± 0.05	60	26	2520
58	700	6.3	0.3 ± 0.05	60	22	2520
59	700	6.3	0.3 ± 0.05	60	24	2520
60	700	6.3	0.3 ± 0.05	60	23	2520
61	700	6.3	0.3 ± 0.05	70	31	2520
62	700	6.3	0.3 ± 0.05	70	26	2520
63	700	6.3	0.3 ± 0.05	70	28	2520
64	700	6.3	0.3 ± 0.05	70	26	2520
65	700	6.5	0.5 ± 0.05	60	3.0	2600
66	700	6.5	0.5 ± 0.05	60	9.0	2600
67	700	6.5	0.5 ± 0.05	60	15	2600
68	700	6.5	0.5 ± 0.05	60	5.7	2600
69	700	6.5	0.5 ± 0.05	60	24	2600
70	700	6.5	0.5 ± 0.05	60	20	2600
71	700	5.5	0.5 ± 0.05	60	18	2200
72	700	5.5	0.5 ± 0.05	60	21	2200
73	700	4.5	0.5 ± 0.05	60	8.3	1800
74	700	4.5	0.5 ± 0.05	60	8.3	1800
75	700	4.5	0.5 ± 0.05	60	9.0	1800
76	700	3.5	0.5 ± 0.05	60	4.2	1400
77	700	3.5	0.5 ± 0.05	60	4.9	1400
78	700	3.5	0.5 ± 0.05	60	5.1	1400

Table 8 describes the substitution of 3-9 mesh silica gel for the previously used 6-16 mesh silica gel to determine the effect of mesh size on the adsorption of TCE. The weight of the 3-8 mesh silica gel was 147 grams, which was identical to the 6-16 mesh silica gel that was used in the cylinder. The coarser silica gel was packed into a 2" NPT stainless steel pipe. The apparent volume for the coarser silica gel was 190 cc, whereas the 6-16 mesh was 150 ml. All the tests in Table 8 removed 700 ppb of TCE from the water. Also held constant was the ozone flow rate at .3 L/M and the temperature at 60° C. The space velocity through the silica gel was varied from 1042 reciprocal hours to 3253 reciprocal hours. Comparing test Run Nos. 99-103 in Table 8 with test Run Nos. 57-60 in Table 7, the coarser mesh appears to reduce the TCE passing through the silica gel to approximately 1% less than when using the finer mesh silica gel. The same silica gel was used throughout this series of tests.

TABLE 8

REMOVAL OF TCE FROM WATER FOLLOWED BY OXIDATION OF  
 THE REMOVED TCE WITH  $O_3$  IN A  $SiO_2$  COLUMN IN  
 THE ABSENCE OF UV LIGHT

10

Test Run No.	TCE (ppb)	Gas Flow Thru D-TOX (L/M)	2% $O_3/O_2$ Flow (L/M)	Temp. (°C)	% of TCE Remaining	Velocity (hr <sup>-1</sup> )
15						
79	700	6.3	$0.3 \pm 0.05$	60	6.7	1989
80	700	6.3	$0.3 \pm 0.05$	60	5.6	1989
20						
81	700	6.3	$0.3 \pm 0.05$	60	18	1989
82	700	6.3	$0.3 \pm 0.05$	60	19	1989
83	700	6.3	$0.3 \pm 0.05$	60	18	1989
25						
84	700	6.3	$0.3 \pm 0.05$	60	16	1989
85	700	6.3	$0.3 \pm 0.05$	60	23	1989
86	700	6.3	$0.3 \pm 0.05$	60	22	1989
30						
87	700	5.3	$0.3 \pm 0.05$	60	18	1674
88	700	5.3	$0.3 \pm 0.05$	60	11	1674
35						
89	700	4.3	$0.3 \pm 0.05$	60	6.0	1358
90	700	4.3	$0.3 \pm 0.05$	60	6.1	1358
91	700	4.3	$0.3 \pm 0.05$	60	6.3	1358
40						
92	700	3.3	$0.3 \pm 0.05$	60	4.8	1042
93	700	3.3	$0.3 \pm 0.05$	60	5.4	1042
94	700	3.3	$0.3 \pm 0.05$	60	4.3	1042
45						
95	700	3.3	$0.3 \pm 0.05$	60	7.1	1042
96	700	3.3	$0.3 \pm 0.05$	60	14	1042
50						
97	700	5.3	$0.3 \pm 0.05$	60	14	1674
98	700	5.3	$0.3 \pm 0.05$	60	18	1674
55						
99	700	8.3	$0.3 \pm 0.05$	60	13	2621
100	700	8.3	$0.3 \pm 0.05$	60	21	2621

TABLE 8 (continued)

Test Run No.	TCE (ppb)	Gas Flow Thru D-TOX (L/M)	2% O <sub>3</sub> /O <sub>2</sub> Flow (L/M)	Temp. (°C)	% of TCE Remaining	Velocity (hr <sup>-1</sup> )
101	700	8.3	0.3 ± 0.05	60	16	2621
102	700	8.3	0.3 ± 0.05	60	17	2621
103	700	8.3	0.3 ± 0.05	60	15	2621
104	700	10.3	0.3 ± 0.05	60	22	3253
105	700	10.3	0.3 ± 0.05	60	24	3253
106	700	10.3	0.3 ± 0.05	60	25	3253

From these series of tests it can be concluded that:

1. The ozone without ultraviolet light can remove 90% or better of the TCE from a saturated air stream under conditions where the silica gel is held at a temperature of 60° C and the ozone input flow at 2% by weight in oxygen is 0.3 L/M, the concentration of the TCE in the water is at 50 ppb and the space velocity is about 2500 reciprocal hours. If higher concentrations of TCE are in the water, the space velocity should be reduced in proportion to the concentration of the TCE.

2. Other variables affecting TCE removal include the mesh size of the silica gel and the ozone input flow. The amount of water contained in the silica gel appears to have an effect on the amount of TCE that can be absorbed and therefore oxidized by the ozone.

Ultraviolet light alone removes 80% or better of the TCE with space velocities in the 2400 reciprocal hour range. The addition of ozone with ultraviolet light may enhance the oxidation of the TCE.

#### Other Applications

The basic organic halogenated compound detoxification unit (using a bed of either silica gel or quartz chips and irradiation with ultraviolet light and/or exposure to ozone) can also be used in a wide variety of industrial applications other than those previously described. These halogenated compounds are used and/or produced in dry cleaning, in incinerators which produce these compounds as offgases, in many chemical processes, following chemical spills, and in chemical storage tanks; the unit could be used for detoxification in any of these systems. It is also hypothesized that a smaller-mesh silica gel bed could be used as a purification system for water which contains bacteria. It is known that ultraviolet light kills bacteria and it is believed that passing bacteria contaminated water through the detoxification unit would increase the rate of bacterial destruction.

It is believed that electromagnetic radiation with wavelengths shorter than ultraviolet light may also effectively decompose the aforementioned volatile organic halogenated compounds when used to irradiate a bed of silica gel or quartz chips in a system wherein a gaseous mixture of these compounds is passed through the bed. Additionally, it is believed that materials other than silica gel or quartz chips, which possess the ability to absorb and concentrate volatile organic halogenated compounds, can be used with the detoxification units of the invention.

Other modifications and variations of the present invention are possible without departing from the spirit hereof; the invention is therefore limited only by the scope of the claims which follow.

#### Claims

1. An apparatus for decomposing organic compounds contained in gases and aqueous solutions, comprising:

a) a reactor tank for simultaneously exposing a contaminated aqueous solution to ozone and ultraviolet radiation to oxidize organic compounds in the solution and to volatilize organic compounds from the solution, said reactor tank having at least one influent port for incoming solution and at least one effluent port for outgoing solution, and said reactor tank having at least one gas diffuser tube proximal to the influent port for introducing ozone into the contaminated solution in the tank, and said reactor tank containing ultraviolet irradiation means;

b) ozone generator means coupled to at least one gas diffuser tube for generating ozone from air to produce an ozone-air mixture, and for introducing the ozone-air mixture into said reactor tank for reaction with the contaminated solution; and

c) a detoxification unit coupled to the reactor tank for decomposing volatilized organic halogenated compounds contained in gases, said detoxification unit having a plurality of irradiating means for irradiating the volatilized organic compounds, and having a porous adsorbent bed for adsorbing ozone and organic compounds arranged such that said porous adsorbent bed is surrounding said irradiating means and at a distance effective to promote reduction of said volatile organic halogenated compounds in said gases.

2. The apparatus of Claim 1 wherein said irradiating means are enclosed in quartz sheaths in said detoxification unit.

3. The apparatus of Claim 1 or 2 wherein said reactor tank further comprises a plurality of chambers formed by a plurality of longitudinal baffles to facilitate flow of the influent solution in the chambers from the influent port to the effluent port of the reactor tank, said baffles disposed parallel to each other and having a length which is less than the width of the reactor tank to allow passage of the solution between the channels formed by said baffles.

4. The apparatus of any one of the preceding claims wherein said irradiation means comprise a plurality of ultraviolet lamps, said lamps placed vertically in the chambers of the reactor tank relative to the longitudinal placement of the baffles.

5. The apparatus of any one of the preceding claims wherein said porous adsorbent bed comprises silica gel.

6. The apparatus of any one of the preceding claims wherein said detoxification unit includes means for heating said porous adsorbent bed.

7. An apparatus for decomposing volatile organic halogenated compounds contained in gases comprising:

a) a housing having a gas supply port, a gas exhaust port, and a gas flow path between said gas supply port and said gas exhaust port;

b) a porous adsorbent bed located in said gas flow path, wherein said porous adsorbent bed is capable of adsorbing ozone and volatile organic halogenated compounds from the gaseous state; and

c) means for irradiating said porous adsorbent bed with ultraviolet light, said porous adsorbent bed surrounding said irradiating means and at a distance effective to promote reduction of said volatile organic compounds in said gases.

8. The apparatus of Claim 7 further comprising means for exposing said porous adsorbent bed to ozone.

9. An apparatus for decomposing volatile organic halogenated compounds contained in gases comprising:

a) a housing having a gas supply port, a gas exhaust port, and a gas flow path between said gas supply port and said gas exhaust port;

b) a porous adsorbent bed located in said gas flow path, wherein said porous adsorbent bed is capable of adsorbing ozone and volatile organic halogenated compounds from the gaseous state; and

c) means for exposing said porous adsorbent bed to ozone to promote reduction of said volatile organic compounds in said gases.

10. A method for decomposing volatile organic halogenated compounds in gases comprising passing gas carrying the volatile organic compounds through a porous adsorbent bed of silica gel while irradiating the porous bed with ultraviolet light and/or exposing the porous adsorbent bed to ozone for an amount of time effective to decompose the volatile organic halogenated compounds in said gases.

11. The method of claim 10 wherein said ozone is added to the gas comprising the volatile organic compounds prior to passing the gas through the porous adsorbent bed of silica gel.

12. The method of claim 10 or 11 wherein the temperature of said porous bed is controlled to approximately 50° to 70° C to promote the decomposition of said volatile organic halogenated compounds.

13. The method of any one of claims 10 through 12 wherein said gases are one of dry, humid and water saturated.

14. The method of any one of claims 10 through 13 carried out in the apparatus as defined in any one

of claims 1 through 9.

15. A method for decomposing volatile, organic halogenated compounds contained in aqueous solutions comprising:

- 5 a) volatilizing the volatile, organic halogenated compounds from a contaminated aqueous solution to a gaseous carrier by passing said gaseous carrier through said aqueous solution; and
- b) passing said gaseous carrier through a porous adsorbent bed of silica gel while exposing said porous adsorbent bed to ultraviolet light and/or ozone to appreciably decompose the volatile organic halogenated compounds in said gases.

10 16. The method of claim 15 wherein said contaminated aqueous solution is continuously flowing and further comprising recycling said gaseous carrier to further remove organic halogenated compounds by returning said gaseous carrier to said continuously flowing aqueous solution to volatilize the volatile, halogenated compounds and passing said returned gaseous carrier through the porous adsorbent bed while exposing said porous adsorbent bed to ultraviolet light and/or ozone.

15 17. The method of claim 15 or 16 carried out in the apparatus as defined in any one of claims 1 through 6.

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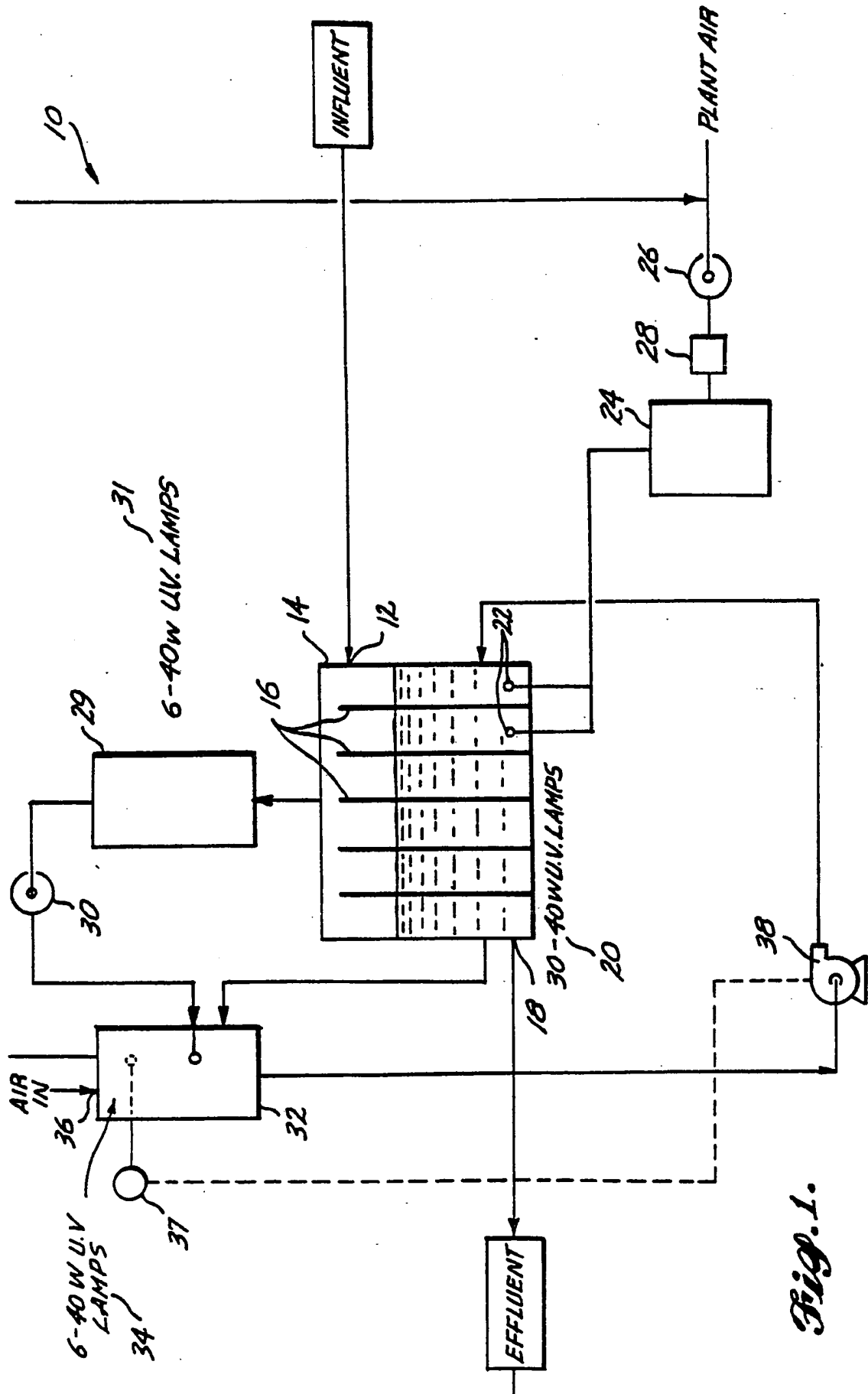
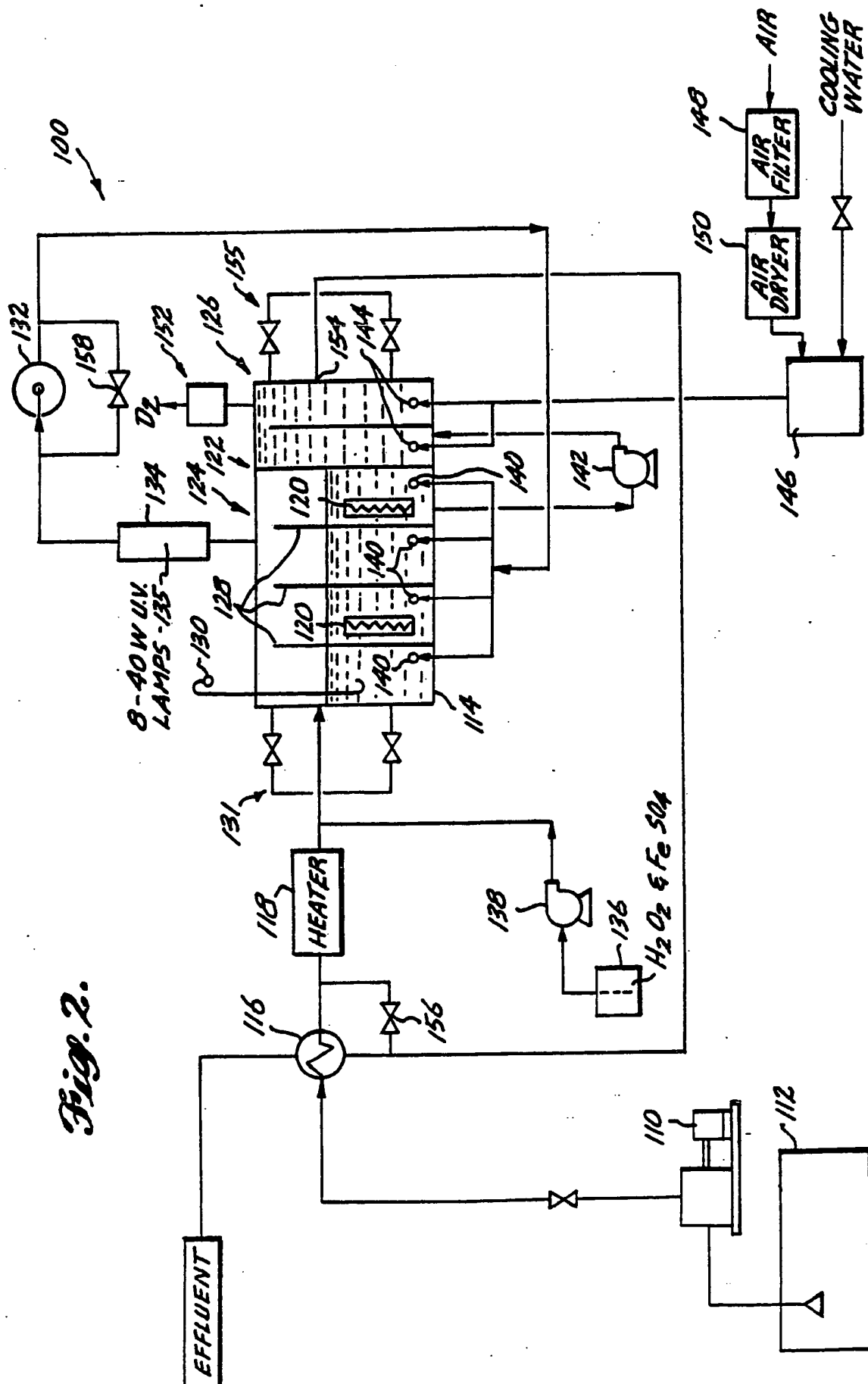


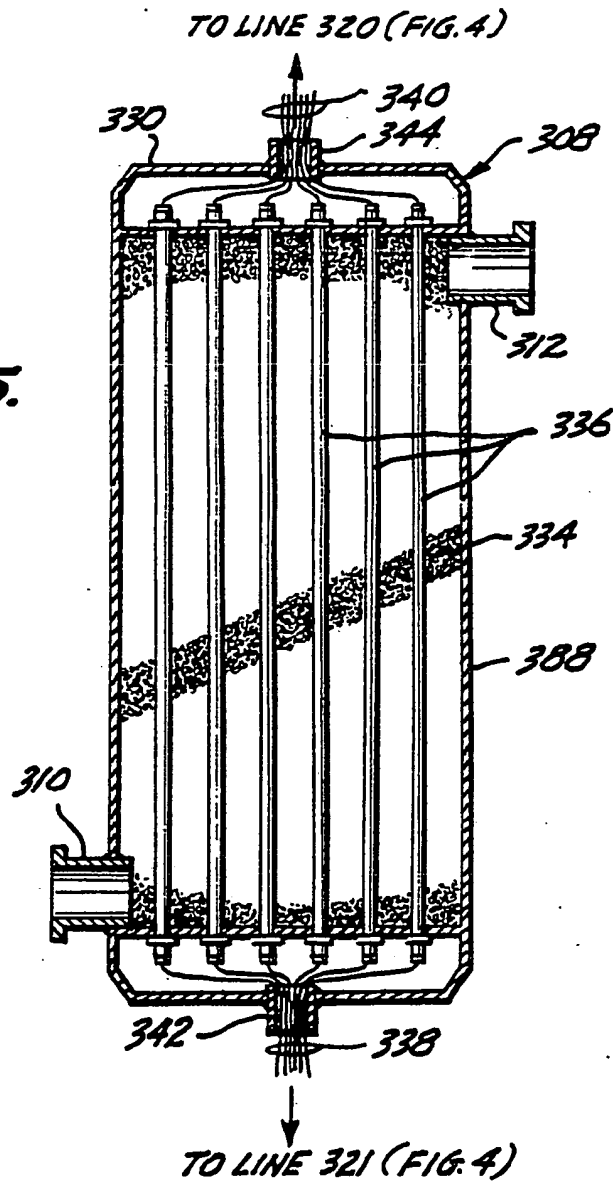
Fig. 1.



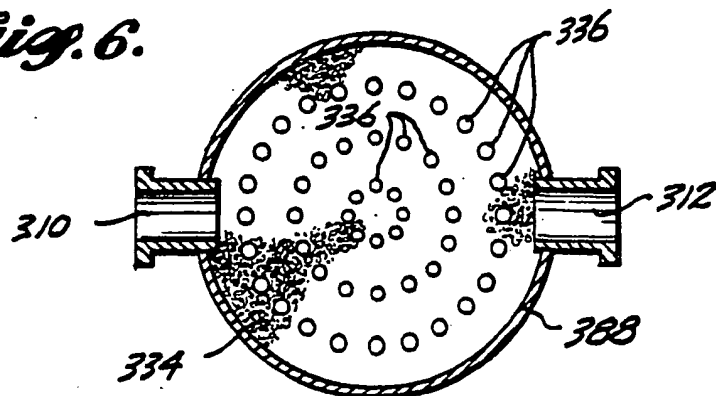




*Fig. 5.*



*Fig. 6.*



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54 **Decomposition of volatile organic halogenated compounds contained in gases and aqueous solutions.**

57 The invention is a method and apparatus for decomposing volatile organic compounds contained in contaminated gases and aqueous solutions. Volatile organic halogenated compounds contained in aqueous solution are removed by volatilizing the compounds from the solution to a gaseous carrier and passing the gaseous carrier through a porous adsorbent bed of silica gel while irradiating the bed with ultraviolet light and/or exposing the bed to ozone. Volatile organic halogenated compounds in a gas are removed by passing the gas through a porous adsorbent bed of silica gel while irradiating the bed with ultraviolet light and/or exposing the bed to ozone.

**EP 0 360 941 A3**



DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
E	US-A-4 780 287 (J.D. ZEFF et al.) * the whole document * ---	1-17	B 01 D 53/34 C 02 F 1/32 C 02 F 1/78
A	DE-A-2 854 462 (GESELLSCHAFT FUER STRAHLEN- UND UMWELTFORSCHUNG) * claims 1,3 * ---	1,7	
A	DE-C-2 462 995 (C.F. SPIESS & SOHN GMBH) * claims 1,2 * ---	1	
A	EP-A-0 261 987 (SOLARCHEM RESEARCH) * claims 1,2 * ---	1,4	
A	PATENT ABSTRACTS OF JAPAN vol. 11, no. 273 (C-445)(2720), 4 September 1987; & JP-A-6274484 (TOSHIBA CORP.) 06.04.1987 * the whole document * ---	1,4,15	
A	PATENT ABSTRACTS OF JAPAN vol. 12, no. 5 (C-467)(2852), 8 January 1988; & JP-A-62163730 (EBARA INFILCO CO.) 20.07.1987 * the whole document * -----	1	TECHNICAL FIELDS SEARCHED (Int. Cl.4)  B 01 D B 01 J C 02 F
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 10-09-1990	Examiner BERTRAM H E H
<b>CATEGORY OF CITED DOCUMENTS</b>  X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document  T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ..... & : member of the same patent family, corresponding document			